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CONCERNING CERTAIN CRITERIA FOR DISCRIMINATION OF THE AGE OF GLACIAL DRIFT SHEETS AS MODIFIED BY TOPOGRAPHIC SITUATION AND DRAINAGE RELATIONS[1]

WILLIAM C. ALDEN

Between the limits of the drift sheets of Wisconsin age in southern Wisconsin and northern Illinois and the Driftless Area there is exposed a deposit of glacial drift of pre-Wisconsin age, having certain characteristics and relations which are of some significance in their bearing on the question of the criteria to be regarded as indicating difference of age in glacial drift sheets—a question of prime importance in the study of the Pleistocene deposits.

The drift under discussion mantles the slopes and uplands on either side of Rock and Sugar rivers and extends thence westward to the Driftless Area (Fig. 1). In southern Wisconsin the writer's observations were extended westward to the limit of the drift but in Illinois they were confined to a belt ten to twenty miles wide on each side of Rock River.

The filling of the main valleys is, in part at least, composed of outwash from the glaciers of the Wisconsin stage and this filling is not included in the present discussion. The upland drift consists principally of a sheet of moderately compact, highly calcareous clayey till which is practically identical in character and lithologic composition throughout the area examined by the writer.

In places, especially near the surface, the drift is loose and sandy. About 80 to 85 per cent. of the pebbles and bowlders imbedded in this till, as shown by many observations, and by the average of 71 analyses made by counting, are from the local limestones. About 3 per cent. are sandstones, shales, and quartzites, which are probably mostly of local origin, and about 14 per cent. crystallines of Canadian

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[1] Published by permission of the Director of the U. S. Geological Survey. Read before the Geological Society of America, Baltimore Meeting, December 30, 1908.

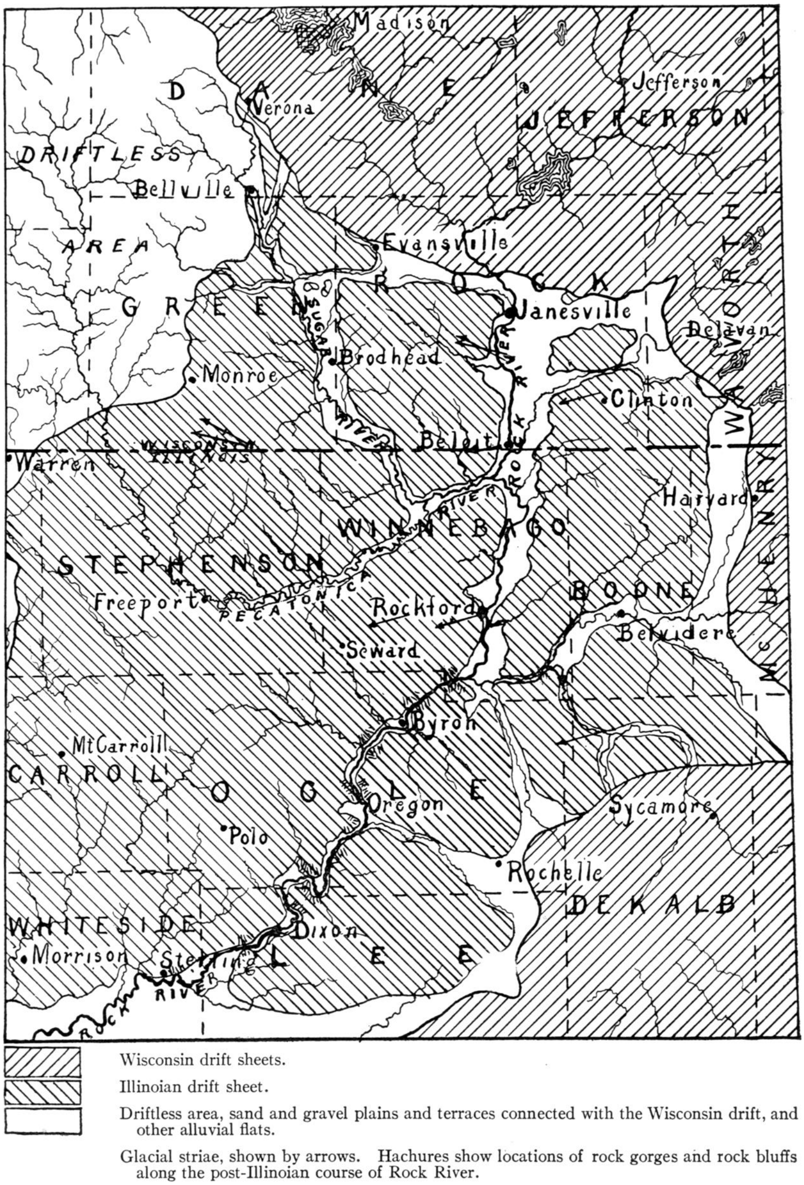

FIG. 1.—Glacial map of portions of southern Wisconsin and northern Illinois. (Boundaries for that part of Illinois not examined by the writer from Frank Leverett, "Illinois Glacial Lobe," *Mon. U. S. Geol. Surv.*, XXXVIII, Pl. XII.)

derivation. The limestone pebbles are mostly from the Galena and Trenton formations,[1] which underlie the drift throughout the greater part of the area, and partly from the Niagara limestone whose west margin lies a few miles east of the Wisconsin terminal moraines. The principal difference in the lithologic composition in the several parts of the area consists of a decrease in the content of Niagara limestone as one goes westward farther from the margin of that formation, with a reciprocal increase in the percentage of Galena and Trenton. Niagara pebbles are, however, seen in almost every exposure westward to the limit of the drift, the average shown by analyses being nearly 24 per cent. of the whole. The presence of this Niagara constituent with an occasional pebble of Devonian rock shows clearly the easterly derivation of the drift which is in consonance with the evidence of direction of the ice movement as shown by striae observed at several places. The striae, as shown upon the map, have bearings shifting from S. 75° W. east of Rock River and near Rockford, to due west at Beloit, N. 62° to 75° W. near Janesville, and N. 35° to 75° W. southeast of Monroe, as the ice closed in about the southeast side of the Driftless Area. At no place has the writer observed this till sheet to be overlain by any deposit other than sand, clayey loam, and loess, which could not have been, or probably was not derived from this drift by weathering or erosion.

It is quite possible, if not probable, that this till is underlain in part at least by older drift, but that question is not here under discussion. So far as the writer has observed there is no good ground for differentiating the drift exposed at the surface into deposits of more than one stage of glaciation. No intercalated soils, weathered zones, vegetal or other fossiliferous deposits are known to separate one part of this drift from another. Such as have been penetrated in wells or otherwise located occur beneath considerable thicknesses of this drift and probably represent an earlier stage of deglaciation.

The drift under discussion is clearly older than that bordered by the Wisconsin terminal moraines on the north and east, and it is believed to correspond in age with the Illinoian drift sheet which covers so large a part of Illinois farther south. There are, however, certain differences in the topography, amount of erosion, and depth and degree of surficial alteration of this drift in different parts of the area, which are very confusing when one attempts to apply the usual criteria for the discrimination of the age of drift sheets and which might be, and indeed have been considered indicative that this drift represented more than one stage of glaciation. It is the purpose of this paper to point out the differences and to suggest an interpretation of them which may perhaps find application in other areas.

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[1] The Paleozoic formations are referred to in this article by the names in use for them in eastern Wisconsin by the Wisconsin Geological and Natural History Survey.

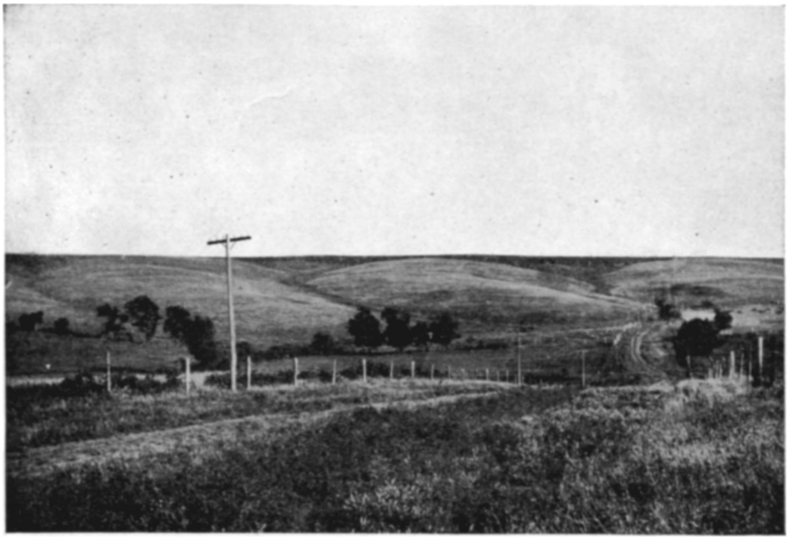

FIG. 2.—Erosion topography on Galena and Trenton limestones thinly covered with Illinoian drift three miles east of Monroe, Wis. Very little if any of the upland plain remains not reduced to slope.

The first of these differences to be considered are topographic. The character of the valley bottoms is to be neglected as due to subsequent filling, only that of the slopes and uplands being considered. In that part bordering Sugar River and extending thence westward to the Driftless Area the surface is much dissected with reliefs of 200 to 300 feet. At no places does a square mile of the upland remain and the drift-mantled slopes show drainage lines at intervals of 10 to 30 rods, which often notch the crests of the divides (Fig. 2). The topography as a whole closely resembles that of the Driftless Area to the west (Fig. 3). Judging by the *topography* of the slopes and uplands alone one might say that the drift here was as old as the Kansan. Eastward to Rock River there is a little less relief and not quite so much dissection of slope, yet there is but little upland left and the topography looks mature. There are, however, in several places west of Rock River indications in the topography itself that the post-glacial drainage development is not as mature as appears from a more general view. At quite a number of places small drift dams in the valleys have diverted the drainage to one side where small gorges have been cut through adjacent rock spurs. These drift dams are small and their crests are usually well below the general upland level. The basins above these dams, however, are clearly not due to post-glacial erosion. There is thus positive evidence that the valleys were not entirely filled by drift and subsequently re-excavated, and hence that the present relief is only in small part due to post-glacial erosion. While there is thick drift in many places in the valleys, the upper slopes were usually but thinly mantled with drift

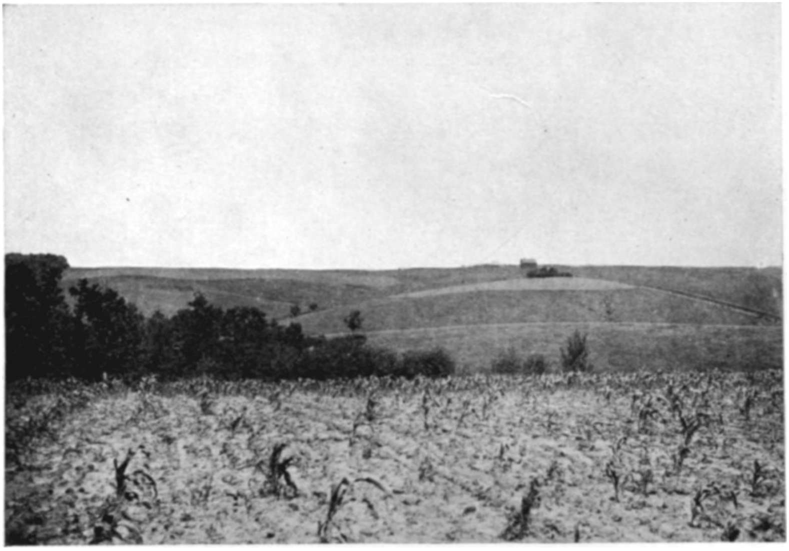

FIG. 3.—Erosion topography on Galena and Trenton limestone in the Driftless Area northwest of Monroe, Wis. Very little if any of the upland plain remains not reduced to slope.

and the apparent maturity is largely due to the fact that the pre-glacial topography was but slightly masked and not wholly buried as it was within the terminal moraines of the later sheets. The post-glacial drainage, with the exception of these slight divergences, has followed pre-glacial lines, and here the gradients of the drift-mantled slopes were sufficiently high to favor rapid erosion.

East of Rock River the area covered by this same drift has a more youthful aspect, being a gently undulating upland plain with slight drumloidal ridges and occasional undrained sags. The borders of the tract are trenched by drainage lines but not greatly dissected. The amount of erosion of this upland, which extends southward to the valley of the Kishwaukee in southern Boone County, Illinois, appears but little greater than in similarly situated tracts within the Wisconsin terminal moraines, and, judging from these features alone, one would be very apt to conclude that the drift east of Rock River was considerably younger than that west of Sugar River, if not younger than that between the two streams.

Passing to the upland prairie west of Rock River in Winnebago, Stephenson, Ogle, Lee, and Whiteside counties, Illinois, one finds extensive, undissected tracts, nearly flat or very gently sloping (Figs. 4 and 5). Only the borders of these tracts, where abrupt slopes drop down to the valleys, appear to be eroded. From this condition there is a gradual transition northward to the rather mature topography between Rock and Sugar rivers. We have thus distinct topographic differences in different parts of the area which affect the interpretation of the glacial history.

On examining the degree of surficial alteration of this drift also notable differences appear. West of Rock River in Illinois, where there is such slight drainage dissection, the drift, beneath the thin coating of stoneless clayey loam or loess which is generally present, exhibits striking evidence of long exposure to leaching and oxidation. In many places but a scattering of pebbles lies between the loess or loam and the weathered surface of the limestone and these pebbles are all of the more insoluble kinds of rocks, mostly dense, fine-grained crystallines, cherts, quartzites, and vein quartz. Where there is a few feet of drift it is generally oxidized to a dark brownish color, is rather compact and sandy, not loose sand, but crumbling when dry into little chunks, and the calcareous constituents are almost entirely removed. Where greater thicknesses are exposed, such as 5 or 10 feet or more, a very striking condition is revealed (Fig. 6). The body of the drift is found to be fresh, slightly altered, highly calcareous, clayey till, of light buff, pinkish, bluish, or grayish tint, in which the crystalline pebbles are sound with the exception of some of the diorites, or more basic granites. Fully 80 per cent. and often 85 to 90 per cent. of the pebbles in this unaltered part of the drift are limestone and these are undecayed and have smooth, clean surfaces, often highly polished and delicately striated. Within two or three feet of the top of the till and the base of the loess, however, there is an abrupt change in character and appearance. Passing upward the drift becomes dark brownish in color, the clayey matrix is found to be nearly or quite leached of its lime carbonate, and the few limestone pebbles which remain are either so rotted as to crumble between the fingers or the surfaces have been roughly etched by solution. In places only a soft yellow powder marks the former position of a limestone pebble. Within a few inches this grades upward into a dark-red layer from

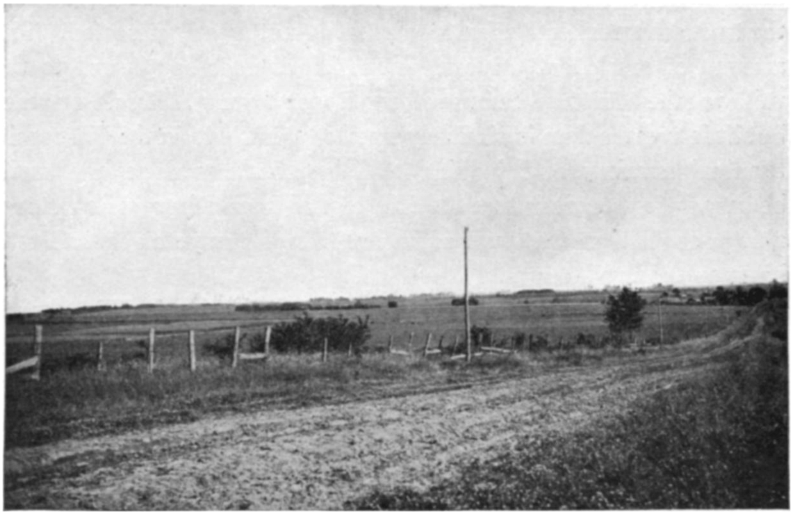

FIG. 4.—Illinoian upland drift plain of remarkably long, gentle, uneroded slope. The drift is probably of moderate thickness, overlain by a few feet of loess and underlain by Galena limestone. Three miles northeast of Seward, Ill.

which every particle of limestone including the pebbles has been removed, leaving only a small amount of sticky red clay, the residuum of complete disintegration of the limestone, binding the insoluble constituents, sand grains, quartz, quartzite, chert, and dense, fine-grained crystallines into a compact gritty mass. This layer is usually about 2 feet, sometimes 3 feet in thickness, and the change from the unaltered drift below takes place with remarkable abruptness generally within less than a foot—often within the space of a few inches. The red till is not a distinct deposit, for the change is usually gradual, though occurring within so small a distance. If the high percentage of calcareous material present in the unaltered part of the till is supposed originally to have continued to the surface of the deposit, as there is every reason for thinking it did, then this residual layer of insoluble constituents must represent but 20 per cent. of the thickness subjected to alteration. In other words, the 3 or 4 feet of residual till represents the concentration of the insoluble constituents in an original thickness of 15 or 20 feet of unaltered till. Even if for conservatism we consider the calcareous and other soluble

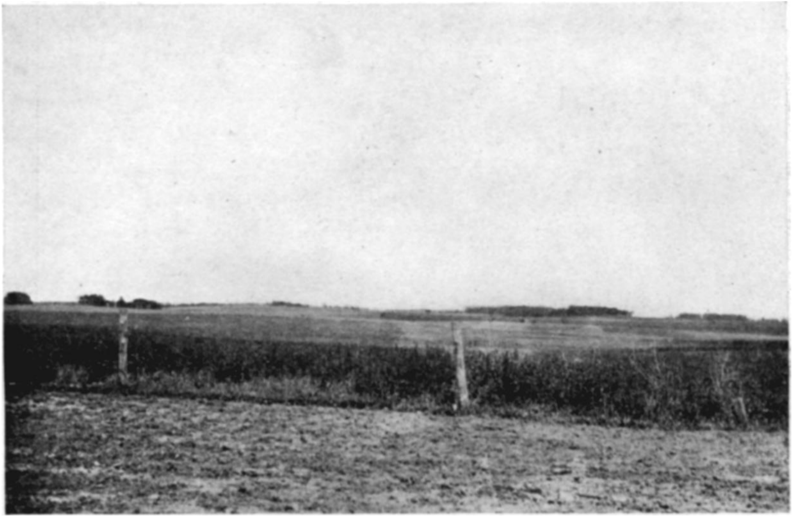

FIG. 5.—Illinoian upland drift plain, five miles west of Rockford, Ill. Galena limestone covered with 1 to 40 feet of drift. There are here extensive tracts of upland and long gentle slope but little affected by erosion.

material as comprising but two-thirds of the unaltered drift the amount of alteration accomplished is considerable in reducing a thickness of 9 to 12 feet to 3 or 4 feet of residuum. This is much greater than the amount of alteration of the Wisconsin drift and indicates a much longer time of exposure, a length of time seemingly out of harmony with the amount of erosion which has been accomplished in this part of the area—for this residual drift is well developed where the plains are least dissected by erosion. We have thus the combination of rather old drift and very young topography.

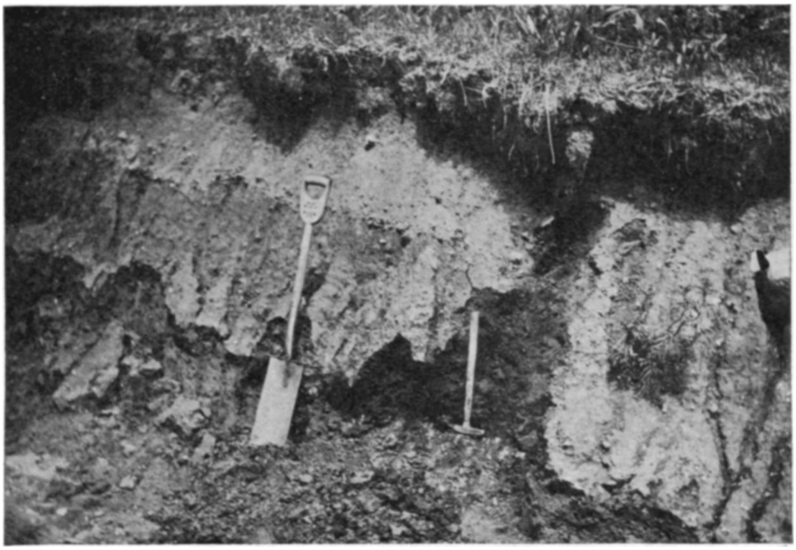

FIG. 6.—Exposure of Illinoian drift one-half mile south of Seward, Ill. The section shows loess 1½ feet—dark-red, residual, weathered Illinoian till from which all limestone pebbles and finer calcareous material have been removed by solution, 2 to 3 feet—buff calcareous till with abundant pebbles of Niagara and Galena limestone. The length of the hammer, 16 inches, shows the zone of gradation from residual to unaltered calcareous till.

Added to these confusing conditions, one examining this tract west of Rock River in Illinois, especially along the borders of the upland, and in that part west and northwest of Rockford, frequently finds unaltered till coming right up to the surface or to the base of the thin coating of loess or loam, or else the unoxidized till has only the calcareous material of the clayey matrix leached out to depths of one or two feet, while the limestone pebbles are fresh and sound. There are also occasional eskers and knolls of fresh limestone drift rising 5 to 25 feet above the surrounding plain of weathered drift. The relations are such that one might easily be led to the conclusion that the old drift sheet was overridden by a later advance of an ice sheet, which was thin and caused but little removal of the pre-existing drift, and which, on melting, left a scattered deposit of fresh drift upon the old.

East of Rock River where the most youthful topography is found the extremes in degree of weathering above noted are less frequently seen, there being the more usual combination of oxidation to a dark buff or brownish color and fairly complete leaching of the fine calcareous elements from the clayey matrix, but without removal of the limestone pebbles, though the surface of such pebbles in the upper part of the zone of weathering may be somewhat etched by solution. In some exposures the upper part of the drift is reduced to the residual condition and a few instances were noted where the matrix was leached of lime carbonate to depths of 10 to 15 feet, but this is rare. The average depth of surficial alteration east of the river is 4 or 5 feet. Were exposures more frequent in the uneroded parts of this upland tract the average amount of alteration might be found to be greater than this.

In the tract between Rock and Sugar rivers where the topographic development appears considerably more mature, and between Sugar River and the west limit of the drift where the amount of dissection seemingly approximates that of the Driftless Area, the drift on the slopes and crest is generally very thin, often little more than scattered pebbles, mostly of the insoluble varieties between the loamy clay soil and the weathered surface of the limestone. In many places, however, especially on lower slopes and in the valleys, considerable thicknesses of drift remain, sometimes 100 to 200 feet or more. Where even a few feet of this till are exposed the unaltered part is found to be the same highly calcareous drift as seen elsewhere. Tests at 25 or 30 exposures show the matrix of the till to be leached of its calcium carbonate to an average depth of about 4 feet, but the limestone pebbles are not removed. This depth includes the thin coating of brown non-calcareous loamy clay which generally overlies the drift north of the state line. The leached top of the till is usually oxidized to a buff or brownish tint, but beneath this there is little or no evidence of alteration. At a few of the exposures basic crystalline pebbles in the weathered zone are considerably disintegrated but most of the crystalline and limestone pebbles are fresh, clean, and sound, showing little more alteration than in the late Wisconsin drift. Nowhere in this part has the residual condition of weathered drift been found so well developed or at least so well preserved as it is near Rockford, Illinois.

Taken altogether there is in this area of pre-Wisconsin drift a rather confusing lot of differences which must be harmonized if one is to reach any definite conclusion as to the relative age of the drift exposed. The unaltered drift is practically identical in character and lithologic composition throughout, the only differences in the latter being such as would be expected from an ice sheet moving in a westerly direction across the different rock formations which underlie the drift in different parts of the area or immediately to the eastward. The only questionable element is the derivation of quartzite pebbles, which need not be considered in this connection.

The differences in the present topography appear to be due very largely to differences in the pre-glacial topography which in the northwest was only mantled by the drift and not entirely obliterated; and in part to a retardation of erosion in certain parts of the area due to the relocation of Rock River, following the melting of the Illinoian ice sheet.

The character of the pre-glacial topography depends largely on the relations of the limestones and sandstones to the zone of erosion. The greater part of the area, that is, the slopes and uplands, is underlain by the Galena and Trenton limestones. These and the underlying formations have very low dips, curving over the low broad axis of the southern end of the Wisconsin island. Going toward this island, that is, up the low dip, the edges of the formations are beveled off and successively lower formations rise in the zone of erosion. The slopes developed on the limestones were rather long and gentle, but where the friable St. Peter sandstone rose into the higher levels there was more rapid erosion, a steepening of the slopes, and a greater amount of dissection was accomplished. This standstone rose well up in the slopes north of the state line and here also Rock River cut down into the Potsdam sandstone, so that the uplands of Rock and Green counties west of Rock River were much dissected and almost wholly reduced to slope. East of Rock River, however, the southeasterly dip depressed the St. Peter sandstone in the east slope of the valley and carried it wholly below the bottom of the pre-glacial valley which bordered the eastern upland on the east in Walworth and McHenry counties. This confined the erosion more largely to the horizon of the limestones and as a result there was less dissection east of the river and much of the upland plain was left. Similar conditions resulted from the southward dip south of Pecatonica River on the west side of the Rock Valley. The St. Peter sandstone comes up again locally between Byron and Dixon, Illinois, but here other relations control the final result. The deposition of the drift sheet under discussion mantled these slopes and uplands but, as has been shown, the pre-glacial topography was only masked, not wholly obliterated, so that subsequent drainage for the most part followed earlier courses. Thick deposits were preserved in the valleys, but in the more dissected tracts, especially where the upper slopes were steep, conditions have been favorable for the accomplishment of considerable erosion.

Not only did the character of the pre-glacial topography affect erosion of the drift, but the relocation of Rock River, the master stream, which followed the retreat of the ice front had also some effect. When the glacial margin was melted back to the east side of the pre-glacial Rock Valley above the mouth of Kishwaukee Valley south of Rockford, the accumulated waters from the blocking of the drainage and melting of the ice found outlet across a series of cols and along the intervening valleys between Rockford and Sterling, so that the post-Illinoian stream became located along a new course, that which is now followed between Rockford and the Mississippi. In deepening its valley along this line the river was forced to cut gorges in limestone and sandstone at several points. There is some evidence that this cutting began 100 feet or more above the level of the present stream. Just how much below this level these gorges were cut before the outwash gravels of the Wisconsin stage came in is not known, but it is evident that their erosion must have retarded the work of the main stream and its tributaries throughout the area under discussion.

The fact that almost all of the area west of the Rock and north of the Pecatonica had previously been reduced to slope gave opportunity for considerable erosion there, despite this retardation, but elsewhere the slow process of working back into uneroded uplands had to be undertaken and as a consequence only the margins of the upland tracts have been dissected, while the upland plains, though fairly well drained, are still largely untouched by erosion.

In the relation of the rate of surficial alteration of the drift by leaching and oxidation to the rates of removal of the upper part of the drift by surface wash under these different conditions prevailing in different parts of the area may be found the explanation of the apparent discrepancies noted when attempting to apply the criteria for determining the age of the drift sheet. The discrepancies are apparent rather than real, yet they are none the less confusing. The difficulty is to make the proper allowances and draw the right conclusions.

In the region south of the state line where the extremes of fresh or little weathered drift and of drift reduced to a residual condition are found at the surface or immediately underlying the loess or loamy clay in neighboring exposures, careful examination reveals the fact that in many places at least where the drift is so fresh the topographic relations are such that the weathered upper part may have been removed by slope wash. That it really was so removed seems clear, for many, if not all, of these exposures of fresh drift are on slopes, and where the exposures extend up the slopes as along roads one often finds the fresh drift disappearing under a layer of weathered drift higher up. In some places where the road runs along a gentle slope, where it does not look as though much wash had occurred, fresh drift is exposed at the surface on the down-hill side, while on the up-hill side thoroughly leached and oxidized residual till extends to the full depth of the shallow cut. It may be that a relation so obvious appears scarcely worthy of mention, yet it is one that may be readily overlooked in such situations as here where the erosion of the drift occurred before the deposition of the loess, and the latter obscured the slight topographic expression that resulted.

In the cases of the unaltered drift composing the knolls and ridges no evidence other than the freshness of the drift was noted which might be taken as indicative of their later origin. In these cases it seems that, even if the weathered surficial part has not been removed by erosion, the configuration and structure of the slight elevations may explain their lack of weathering. In the first place, the rounded surfaces of the knolls and ridges rising above the plain shed most of the water falling on them much more readily than do the surrounding plain tracts, especially where the latter have such long gentle slopes such as characterize the area in question. The gravel of the knolls is particularly loose and open so that such of the meteoric water as penetrates, percolates through and out of the gravels very readily and has but a comparatively small contact with the surface of the calcareous particles or pebbles. This is true not only because of the large interspaces allowing rapid passage of water, but also because the total amount of surface exposed by the pebbles is far less than that where the material is finely comminuted as the rock-flour matrix of the till. The result is that while the waters slowly percolating downward into the calcareous till on the plain tract may have relatively large solvent action, so as to remove the finer particles and even the limestone pebbles to the depths indicated above, the limestone pebbles of the knolls and ridges continued unaltered beyond a small amount of cementation in the lower parts of the deposit by lime carbonate carried down from above. On the nearly flat or gently sloping plains surface wash seems to have been reduced to the minimum, while the slow process of leaching out the calcareous elements and oxidizing the ferruginous constituents had its maximum effect. Here the till slowly rotted down. Besides the part which was removed by solution, some of the finest silt may have been carried away by surface wash. This was deposited in the valleys while much of the insoluble part of the clay and the more resistant sand grains and pebbles, the residuum of the leaching process, was left on the unaltered drift.

In those situations, where the topography and the constitution of the drift were such that the rate of leaching and oxidation exceeded the rate of removal of the weathered part by wash, such a residual layer was developed. Where the rate of removal was more rapid or where the two processes nearly balanced each other, fresh drift is exposed at the surface. Where the relations were such that the rate of removal lagged behind the process of alteration, but not so far that there was time for the reduction of the weathered drift to a residual state, such as seems to have been the case on the moderately mature erosion topography west of Rock River in southern Wisconsin, there is the usual condition of leaching of the clayey and sandy matrix to moderate depths and oxidation only to the degree of changing the original pinkish, bluish, or grayish color to a buff or brownish tint.

It is thus evident that the apparent alteration of a single drift deposit by weathering and erosion may vary considerably in different and often closely adjacent parts of a single drainage basin in the same length of time, even where the differences in elevation are but slight and where the climate is the same. It is true that one cannot always see just what the particular relations were which resulted in the different degrees of alteration at two different exposures, and the observed differences are frequently not just what one would expect from reasoning along the line indicated. However, it is well to bear in mind the fact that such differences do occur where there appears to be no adequate ground for assigning the differently affected deposits to distinct stages of deposition. Caution must be used in applying the criteria and good and sufficient grounds for the differentiation should be observed. It is not necessary to enumerate these criteria in this paper. They have been fully treated by competent authorities in other places. It seems to the writer particularly hazardous to assign a more recent age to what appears to be a thin and scattered deposit of fresh, unchanged, or little altered drift, exposed here and there, when the main deposit of the area in question is of similar lithologic composition and has been considerably altered by weathering and erosion, unless a weathered zone, old soil, or vegetal deposit is observed clearly intercalated between the two drifts. It may not be easy to show that a weathered part has been removed by erosion at the particular places where the fresh drift is observed, or that the conditions for erosion, leaching, and weathering were such that no alteration of the upper part of the drift *in situ* was ever accomplished, but the burden of proof certainly lies with the interpretation which postulates distinct stages of glaciation. Differences in texture and conditions of deposition are particularly unsafe, since almost every conceivable variation of this kind may be found in different parts of what is unquestionably a single drift sheet. As has been shown in this discussion, careful scrutiny of the topography, the drainage, and other relations which may affect the apparent amount of surficial alteration by weathering and erosion in the area under investigation may yield an adequate explanation of the differing phenomena without the postulation of distinct stages of glaciation.